Methods and Devices for Coding or Decoding an Audio Signal or Bit Stream

Description

The present invention relates to methods and devices for coding or decoding an audio signal or bit stream which are able to perform error-tolerant entropy coding or decoding and in particular error-tolerant Huffman coding or decoding.

Modern audio coding or decoding methods, which operate according to the standard MPEG layer 3 for example, are capable of compressing the data rate of audio signals by a factor of 12 for example without causing any noticeable deterioration in the quality of these signals. To obtain such a high data rate reduction an audio signal is sampled, resulting in a sequence of discrete-time samples. As is known in this branch of technology, this sequence of discrete-time samples is windowed using suitable window functions to obtain windowed blocks of temporal samples. A block of temporal windowed samples is then transformed into the frequency domain by means of a filter bank, a modified discrete cosine transform (MDCT) or some other suitable method to obtain spectral values which together represent the audio signal, i.e. the temporal section which consists of the block of discrete-time samples, in the frequency domain. Normally temporal blocks which overlap by 50% are generated and are transformed into the frequency domain by means of an MDCT. Because of the special properties of the MDCT, 1024 discrete-time samples for example always result in 1024 spectral values.

It is known that the receptivity of the human ear depends on the momentary spectrum of the audio signal itself. This dependence is reflected in the so-called psychoacoustic model.

Using this model it has long been possible to calculate mask-
ing thresholds in dependence on the momentary spectrum. Mask-
ing means that a particular tone or spectral portion is ren-
dered inaudible when e.g. a neighbouring spectral region has a
relatively high energy. This phenomenon of masking is ex-
ploited so as to quantize the post-transform spectral values
as coarsely as possible. The aim, therefore, is to avoid audi-
ble disturbances in the decoded audio signal while using as
few bits as possible to code, or here to quantize, the audio
signal. The disturbances introduced by quantization, i.e. the
quantization noise, should lie below the masking threshold and
thus be inaudible. In accordance with known methods the spec-
tral values are therefore subdivided into so-called scale fac-
tor bands, which should reflect the frequency groups of the
human ear. Spectral values in a scale factor group are multi-
plied by a scale factor so as to scale spectral values of a
scale factor band as a whole. The scale factor bands scaled
with the scale factor are then quantized, producing quantized
spectral values. It is of course obvious that a grouping into
scale factor bands is not essential. This procedure is, how-
ever, used in the standard MPEG layer 3 and in the standard
MPEG-2 AAC (AAC = Advanced Audio Coding).

A very important aspect of data reduction is the entropy cod-
ing of the quantized spectral values resulting from quantiza-
tion. A Huffman coding is normally used for this. A Huffman
coding entails variable-length coding, i.e. the length of the
code word for a value to be coded depends on the probability
of this value occurring. As is logical the most probable sym-
bol is assigned the shortest code, i.e. the shortest code
word, so that very good redundancy reduction can be achieved
with Huffman coding. An example of a universally known vari-
able-length coding is the Morse alphabet.

In audio coding Huffman codes are used to code the quantized spectral values. A modern audio coder which operates e.g. according to the standard MPEG-2 AAC uses different Huffman code tables, which are assigned to the spectrum according to particular criteria on a sectional basis, to code the quantized spectral values. Here 2 or 4 spectral values are always coded together in one code word.

One way in which the method according to MPEG-2 AAC differs from the method MPEG layer 3 is that different scale factor bands, i.e. different spectral values, are grouped into an arbitrarily large number of spectral sections. In AAC a spectral section contains at least four spectral values, preferably more than four spectral values. The whole frequency range of the spectral values is thus divided up into adjacent sections, where one section represents a frequency band, so that all the sections together cover the whole frequency range which is spanned by the post-transform spectral values.

To achieve a maximum redundancy reduction, a so-called Huffman table, one of a number of such tables, is assigned to each section as in the MPEG layer 3 method. In the bit stream of the AAC method, which normally has 1024 spectral values, the Huffman code words for the spectral values are now in an ascending frequency sequence. The information on the table used in each frequency section is transmitted in the side information. This situation is shown in Fig. 2.

In the case chosen to serve as an example in Fig. 2 the bit stream comprises 10 Huffman code words. If one code word is always formed from one spectral value, 10 spectral values can then be coded here. Usually, however, 2 or 4 spectral values are always coded together in a code word, so that Fig. 2 represents a part of the coded bit stream comprising 20 or 40 spectral values. In the case where each Huffman code word com-

prises 2 spectral values, the code word referenced by the number 1 represents the first two spectral values. The length of this code word is relatively short, meaning that the values of the first two spectral values, i.e. of the two lowest frequency coefficients, occur relatively often. The code word with the number 2, on the other hand, is relatively long, meaning that the contributions of the third and fourth spectral coefficients in the coded audio signal are relatively infrequent, which is why they are coded with a relatively large number of bits. It can also be seen from Fig. 2 that the code words with the numbers 3, 4 and 5, which represent the spectral coefficients 5 and 6, 7 and 8, and 9 and 10, also occur relatively frequently, since the length of the individual code words is relatively short. Similar considerations apply to the code words with the numbers 6 - 10.

As has already been mentioned, it is clear from Fig. 2 that the Huffman code words for the coded spectral values are arranged in linearly ascending order in the bit stream from the point of view of the frequency in the case of a bit stream which is generated by a known coding device.

A big disadvantage of Huffman codes in the case of error-afflicted channels is the error propagation. If it is assumed e.g. that the code word number 2 in Fig. 2 is disturbed, there is a not insignificant probability that the length of this erroneous code word number 2 will also be changed. This thus differs from the correct length. If, in the example of Fig. 2, the length of the code word number 2 has been changed by a disturbance, it is no longer possible for a decoder to determine where the code words 3 - 10 start, i.e. almost the whole of the represented audio signal is affected. Thus all the other code words following the disturbed code word cannot be decoded properly either, since it is not known where these

code words start and since a false starting point was chosen because of the error.

As a solution to the problem of error propagation European patent No. 0612156 proposes that some of the code words of variable length should be arranged in a raster and the other code words should be assigned to the remaining gaps so that the start of a code word can be more easily identified without complete decoding or in the event of a faulty transmission.

The known method provides a partial remedy for error propagation by resorting the code words. A fixed place in the bit stream is reserved for some code words and the spaces which are left can be occupied by the remaining code words. This entails no extra bits, but prevents error propagation among the resorted code words in the event of an error.

The decisive parameter for the efficiency of the known method is how the raster is defined in practice, i.e. how many raster points are needed, the raster distance between the raster points, etc. However, European patent 0612156 does not go beyond the general proposition that a raster should be used to curtail error propagation; there are no details as to how the raster should be efficiently structured so as to achieve error-tolerant, and at the same time efficient, coding.

It is the object of the present invention to provide a concept for the error-tolerant and nevertheless efficient coding and decoding of an audio signal or a bit stream.

This object is achieved by a method for coding an audio signal according to claim 1 or 9, by a device for coding an audio signal according to claim 21 or 22, by a method for decoding a bit stream according to claim 23 or 24 and by a device for decoding a bit stream according to claim 25 or 26.

The present invention is based on the finding that the raster already proposed must be fashioned or occupied in a way that permits efficient coding/decoding as well as error-tolerant coding/decoding. Of prime importance here is the fact that the code words, which are obtained by an entropy coding in the form of a Huffman coding, are inherently of different lengths since the greatest coding gain results when the most frequent value to be coded has a code word of the shortest possible length assigned to it. On the other hand a value to be coded which occurs relatively infrequently, even though it has a relatively long code word assigned to it, results in an optimal amount of data viewed statistically. Code words obtained by a Huffman coding thus have different lengths per se.

According to a first aspect of the present invention so-called priority code words are placed at the raster points so that the start of the priority code words can be identified without fail by a decoder via the raster even if there is an error in the bit stream. Priority code words are code words which are psychoacoustically important. What this means is that the spectral values which are coded by so-called priority code words contribute substantially to the auditory sensation of a decoded audio signal. If the audio signal has a high speech content, the priority code words could be those code words which represent lower spectral values, since in this case the important spectral information is located in the low region of the spectrum. If an audio signal has a group of tones in the middle region of the spectrum the priority code words could be those code words which are assigned to the spectral values in the corresponding middle section of the frequency range, since these are then the psychoacoustically important spectral values. Psychoacoustically important spectral values might also be spectral values whose magnitude, i.e. signal energy, is large compared with that of other spectral values in the

spectrum. Code words of less psychoacoustic importance, which
are also called non-priority code words, on the other hand,
fill up the raster. They are not therefore aligned with the
raster points but are "slotted into" the remaining free spaces
once the priority code words have been positioned on the
raster points.

According to the first aspect of the present invention, there-
fore, the priority code words, which are assigned to spectral
values which are psychoacoustically important, are so arranged
in a raster that the start of the priority code words coin-
cides with the raster points.

According to a second aspect of the present invention the
spectral values are grouped into spectral sections, a differ-
ent code table being assigned to each of these spectral sec-
tions. The assignment of a code table to a spectral section is
made according to signal statistical considerations, i.e.
which code table is best suited for the coding of a spectral
section. The assignment of a code table to a spectral section
is already known in this branch of technology.

A raster will now be employed which consists of several groups
of equidistant raster points such that the distance between
the raster points of a group of raster points depends on the
code table used for coding a spectral section. In another
spectral section another code table is used so as to obtain an
optimal data reduction. This other code table has a different
group of equidistant raster points assigned to it, the dis-
tance between two raster points of this other group of raster
points depending on the associated code table. The distance
between two raster points in the different groups of raster
points can be determined in at least three ways.

In the first the maximum length of a code word of a code table is ascertained. The separation of two raster points in the raster point group which is assigned to this code table can now be chosen to be equal to or greater than the maximum code word length in the code table, so that there is room in the raster for even the longest code word of this code table. The separation of two raster points of a different group of raster points, which are associated with a different code table, is determined in an analogous way according to the maximum code word length of this other code table.

The second alternative, which will now be described, can also contribute to an increase in the number of raster points. Because of the inherent properties of the Huffman code, less frequently occurring code words tend to be longer than more frequently occurring code words. When the raster point separation is chosen to be equal to or greater than the length of the code word of maximum length in a table, therefore, the code words inserted in the raster are usually shorter than the raster point separation. The raster point separation can thus also be chosen to be smaller than the length of the longest code word of a table. If a code word which doesn't fit into the raster then appears when coding, the remainder which fails to fit into the raster is inserted into the bit stream at some other suitable position which is not aligned with the raster. As a consequence, this "cut-up" code word is no longer effectively protected against error propagation. Since this occurs very rarely, however, it can be accepted in the interests of an increase in the number of raster points.

The third possibility of determining the different raster point separations is to consider not the maximum code word length of a table but the length of the longest code word in a bit stream which actually occurs in a coded spectral section.

According to a third aspect of the present invention, instead of a code word arrangement in the bit stream which essentially increases linearly with the frequency, an arrangement in which the code words are distributed over the frequency spectrum can be used, a method which is also known as "scrambling". This has the advantage that so-called "burst errors" do not lead to erroneous decoding of a complete frequency band but simply to small disturbances in several different frequency ranges.

According to a fourth aspect of the present invention, instead of a code word arrangement which increases linearly with the frequency an arrangement can also be used in which e.g. only each n-th (e.g. each second, or third or fourth, ...) code word is arranged in the raster. In this way it is possible to span the greatest possible spectral region using priority code words, i.e. to protect against error propagation, when the number of possible raster points is less than the number of priority code words.

Furthermore, preference is given to determining the priority code words in such a way as to achieve efficient operation. Preferably this means abandoning the assumption that the psychoacoustically significant code words, i.e. the priority code words, are those which code the spectral values with low frequency. This will often be the case, but does not always have to be so.

Normally priority code words are code words which code psychoacoustically important spectral lines, these usually being spectral values with high energy. It is equally important that spectral lines with high energy do not arise because of errors.

According to the present invention an indicator is used which is already implicitly determined. The indicator depends on the

code table which is used. In the AAC standard there are e.g. eleven code tables with different absolute value ranges. The code table No. 1 comprises e.g. spectral values having an absolute value from -1 to +1, while the code table No. 11 can code spectral values from -8191 to +8191. The higher the code table is the greater is the value range which it permits. This means that code tables with low numbers represent only relatively small values, and thus permit only relatively small errors, while code tables with higher numbers can represent relatively large values and thus also relatively large errors.

If an error occurs in a low code table it may well not be audible since an erroneous spectral line results which, seen absolutely, does not differ that much from the originally correct spectral line. If an error occurs in the highest code table, however, this error can in principle assume any of the absolute values in this code table. If a spectral line coded with the highest code table had a small value, for example, and due to an error during transmission is decoded in the decoder as a spectral line with the highest absolute value of this code table, this erroneous spectral line will certainly be audible.

As far as error tolerance is concerned, the most important code table is therefore the highest code table (in the AAC standard the code table No. 11) since this code table permits escape values in the range from $-2^{13} + 1$ (-8191) to $+2^{13} - 1$ (+8191).

According to a further aspect of the present invention, short windows are used for transient signals in the AAC standard. With short windows the frequency resolution is decreased in favour of a higher temporal resolution. The priority code words are determined in such a way that psychoacoustically significant spectral values, i.e. spectral values at lower

frequencies or spectral values from higher code tables, are sure to be placed on raster points. Scale factor band inter-leaving, a feature of e.g. the AAC standard, is revoked for this purpose.

Preferred embodiments of the present invention are explained in more detail below making reference to the enclosed draw-ings, in which

Fig. 1 shows an example of a rastering according to the second aspect of the present invention of a coded bit stream containing code words; and

Fig. 2 shows an arrangement of code words which increases linearly with the frequency according to the prior art.

To illustrate the present invention, priority code words are shown hashed in Fig. 2, which represents a known arrangement of code words of different lengths which increases linearly with the frequency. In Fig. 2 priority code words are the code words No. 1 - No. 5. As has already been explained above, the code words which are assigned to spectral values of low fre-quency are priority code words if the audio signal e.g. con-tains a high speech content or relatively many low-frequency tones. The code words No. 6 - 10 in Fig. 2 are associated with higher frequency spectral values which, while contributing to the overall impression of the decoded signal, do not greatly affect the auditory sensation and are thus psychoacoustically less significant.

Fig. 1 shows a bit stream with a number of raster points 10 - 18, where the distance between the raster point 10 and the raster point 12 is labelled D1 and the distance between the raster point 14 and the raster point 16 is labelled D2.

As far as exposition of the first aspect of the present invention is concerned, only the part of the bit stream extending from the raster point 10 to the raster point 14 will be considered. The priority code words 1 and 2 are aligned in the raster to ensure that the important spectral portions, which are located in the lower frequency range in the example signal shown in Fig. 2, are not subject to error propagation when decoding. Non-priority code words, which are not hatched in Fig. 1 and 2, are arranged after the code words so as to fill up the raster. It is not necessary for the non-priority code words to fit into the raster in one piece, since the length of a Huffman code word is known from the word itself. A decoder thus knows whether it has read only part of a code word. In this case it will automatically add to the first part of the code word a certain number of bits following the priority code word after the next raster point. It is therefore possible to insert a first part of a non-priority code word in a first free position in the raster and the remaining part at some other place, as is shown for the non-priority code words 7, 8 and 9, each of which has been subdivided into two in the bit stream, namely into 7a, 7b and 8a, 8b and 9a, 9b.

As has already been described, the second part of the bit stream of Fig. 1 illustrates the second aspect of the present invention. If the raster distance D1 were not altered to a smaller raster distance D2, a raster with the spacing D1 in which all the priority code words 1 to 5 are to be arranged would lead to such a long bit stream that there would not, so to speak, be enough non-priority code words to fill up all the spaces remaining in the raster. Therefore only so many priority code words are extracted from an audio signal as can be inserted in the bit stream so that essentially no free places remain, i.e. without causing the bit stream to be extended unnecessarily.

The second aspect of the present invention will now be discussed in detail making reference to Fig. 1. In the case of the coding method according to the standard MPEG-2 AAC, 11 different Huffman code tables can be used for the coding. For the majority of these tables the maximum possible code word length lies between 10 and 20 bits. However, a special table, the so-called "escape" table, encompasses a maximum length of 49 bits. If one were to use the length of the longest code word of all the tables as raster distance D, one would have a raster distance of 49 bits, which would result in a raster of very great width and therefore inefficient for nearly all the tables since the bit stream would be far too long if all the priority code words are to be aligned with a raster point. According to the present invention the width of the raster is therefore adjusted in dependence on the code table which is used. As was mentioned previously, spectral values can be grouped into spectral sections, each spectral section then being assigned a code table which is optimally suited to it taking signal statistical aspects into account. The maximum code word length in one code table normally differs from the maximum code word length of another table, however.

It is assumed that the spectral values represented by the code words 1 and 2 belong to a first spectral section while the spectral values represented by the code words 3 - 10 belong to a second spectral section. The bit stream is then rastered using 2 groups of raster points, the first group of raster points consisting of the raster points 10, 12 and 14, the second group of raster points consisting of the raster points 14, 16 and 18. It is assumed further that the spectral section 0 has been assigned the Huffman code table n and the spectral section 1 has been assigned the Huffman code table m, also that the code word 2 is the longest code word of the table n which has been assigned to the spectral section 0. The raster distance of the first group of raster points is chosen to be

greater than or, preferably, equal to the maximum length of the code word of table n, i.e. of the code word 2 in the example.

On the other hand from the section of the bit stream between the raster point 14 and the end of the bit stream at code word No. 10 it can be seen that in this example the code word with the maximum length of the code table m does not appear in the bit stream. There is thus no code word of length D2 in the bit stream raster denoted by group 2.

According to the second aspect of the present invention the width of the raster is thus chosen depending on the code table which is used. It should be noted, however, that in this case the table used must already be known when decoding in the decoder. This is the case, however, since a code table number is always transmitted as side information for each spectral section, thus enabling the decoder to identify this code table within a specified set of, in this example 11, different Huffman tables.

As has already been mentioned, optimal data reduction can still not be achieved when the raster distance depends on the code table used, as is plain to see just by considering the escape table, which has a length of 49 bits, since, in the case of an escape table, the raster width is adjusted to 49 bits so as to code spectral values of maximum size. Escape tables are employed in order to have relatively short code tables while being able at the same time to code relatively large values using the short code tables in conjunction with an escape table. In the case of a value which exceeds the value range of a code table, the code word for this spectral value assumes a predetermined value, which indicates to the decoder that an escape table has also been used in the coder. If a code table encompasses the values 0 - 2, for example, a

value of 3 in the code table would indicate to the decoder that an escape table has been accessed. The code word with the value 3 of the "basic" code table is simultaneously assigned an escape table value which, in conjunction with the maximum value of the basic code table, constitutes the corresponding spectral value.

According to a further embodiment of the second aspect of the present invention the distance between the raster points of a group (e.g. of the group 1 or group 2) is no longer chosen to be equal to the length of the longest code word of a code table but equal to the length of the longest code word actually occurring in a bit stream which belongs to a code table. This represents a further improvement in respect of the first embodiment of the second aspect of the present invention since the coding efficiency in the escape table is still not optimal despite this method. The maximum length of the code of this table (within a spectrum) is usually considerably shorter for technical coding reasons. The longest code word in the escape table is e.g. 49 bits long.

The longest escape table code word actually occurring in normal audio signals is typically about 20 bits long. It is therefore possible to further increase the number of raster points and thus the number of priority code words which can be aligned with the raster points by transmitting the length of the longest code word of a block. The raster length is then equal either to the actually occurring maximum code word length or the theoretical maximum code word length of the table currently being used, whichever has the minimum value. To determine the minimum it is possible to use either the actually occurring code word of each code table or simply the longest code word of all the code tables in an audio frame. This option also works for non-escape tables, i.e. for "basic"

Huffman tables, but not nearly as efficiently as for the escape tables.

Transmitting the maximum length of a code word in a spectral section or block has another beneficial side effect. The decoder can then detect from the maximum length which has actually occurred whether a longer code word is present in a bit stream which may have been disturbed. Long code words normally signify a high energy of the spectral values. If a very long code word arises due to a transmission error this may result in a highly audible disturbance. Transmitting the maximum length thus provides the means of detecting such an error in the majority of cases and of adopting countermeasures, which might be simply blanking out the excessively long code word or might be some more complicated form of concealment.

It is important to note that as many raster points as possible are wanted for error-tolerant and at the same time efficient coding. The number of raster points is, however, limited by the total length of the bit stream. This should not of course be lengthened as a result of rastering, since there would then be unused places in the bit stream, something which would contradict the philosophy of overall data compression. However, it must also be pointed out that a lengthening of the bit stream may well be accepted in the interests of a high degree of error tolerance in certain applications. Another point to be considered is that a raster should preferably be structured so that as many code words as possible start on raster points. The present invention thus permits effective flexibility in the choice of raster point distance as compared with the prior art. In the absolutely ideal case this flexibility would lead to each code word having a raster point assigned to it, something which involves considerable technical effort. The method of arranging the raster points, i.e. determining the distance between the raster points of each spectral section according

to the relevant code table, permits a very close approximation
to the optimal case, however, especially since not all the
code words are psychoacoustically significant and since all
the psychoacoustically less significant code words can be
slotted into the bit stream between the rastered psychoacous-
tically significant code words so as to leave no unused places
in the bit stream.

According to a third aspect of the present invention the code
words are no longer arranged in the bit stream in a linearly
increasing sequence as regards frequency but the code words
for different spectral values are "scrambled". In Fig. 1 it
can be seen that there is to a certain extent an interleaved
linear arrangement of the code words with frequency since the
hatched priority code words are arranged in order of increas-
ing frequency and the non-priority code words, which are not
hatched, are also slotted into the bit stream in order of in-
creasing frequency. If a so-called "burst" error were now to
occur in the bit stream shown in Fig. 1, i.e. a disturbance
which leads to the corruption of a number of successive code
words, the code words 6, 7a, 2, 3 and 7b for example could be
affected simultaneously.

In the corresponding decoded audio signal a disturbance which
is spectrally relatively wide and thus likely to be distinctly
audible would occur in the spectral band represented by the
priority code words 2 and 3. The problem of burst errors is
not very apparent from the very simple example in Fig. 1. In
practice, however, it can be assumed that there will be many
more than 5 raster points and that burst errors will often ex-
tend over a plurality of raster points, which can lead to a
loss of data for a relatively wide frequency band. It is for
this reason that, according to the third aspect of the present
invention, the priority code words of the spectral values are
preferably no longer arranged in ascending order as to fre-

quency but are "mixed up" in such a way as to have a random or pseudo-random arrangement as regards frequency. The non-priority code words may also optionally be treated in the same way. In the case of a pseudo-random arrangement it is not necessary to transmit any information on the distribution as side information since this distribution can be set in the decoder a priori. As a consequence the loss of successive code words in the bit stream would not lead to the loss of a complete frequency band but simply to a very small loss in several frequency bands. This disturbance would scarcely be audible and could also be concealed more efficiently than the loss of a complete frequency band.

According to a fourth aspect of the present invention, instead of an arrangement of the priority and non-priority code words which increases linearly with the frequency an arrangement can also be used in which e.g. only each n-th code word is arranged in the raster and the remaining code words are slotted between them. As has already been stated, the number of raster points for a bit stream is limited by the total length and the distance between the raster points. If e.g. sampling with low bandwidth is considered, the case can occur that the vast majority of the code words are psychoacoustically significant code words since the whole signal has a theoretically possible useful bandwidth of 8 kHz if a sampling rate of 16 kHz is used. Experience shows that only 30% of the code words can be arranged on raster points, the other 70% being required to fill up the raster completely. This would mean, however, that the important frequency range, the range 0 - 4 kHz for speech signals e.g., cannot be covered or "protected" with priority code words arranged on raster points. To achieve adequate protection against error propagation for the important frequency range, therefore, instead of aligning every priority code word with a raster point this is done only for every second, third, fourth, etc. priority code word, while the other priority code

words fill up the raster without being aligned. If e.g. every second or every third etc. spectral value is known in the low frequency range and the interspersed code words are corrupted during transmission, it may be possible to reconstitute these code words in the decoder using error concealment techniques, e.g. prediction or similar.

The methods and devices for decoding a bit stream operate in such a way as to reflect the cited coding.

In a general method for decoding a bit stream representing a coded audio signal where the coded bit stream has code words of different length from a code table and a raster with equidistant raster points (10, 12, 14), where the code words include priority code words which represent certain spectral values which are psychoacoustically important compared with other spectral values and where priority code words are aligned with raster points, (a) the distance D1 between two adjacent raster points is determined. If the distance between two raster points is known, (b) the priority code words in the coded bit stream which are aligned with the raster points can be resorted so as to obtain an arrangement in which they are ordered linearly as regards frequency and the start of a priority code word coincides with a raster point. The priority code words now appear in the general frequency-linear arrangement shown in Fig. 2, so that (c) the priority code words can now be decoded with a code table with which they are associated so as to obtain decoded spectral values. After (d) transforming the decoded spectral values back into the time domain, a decoded audio signal is obtained, which can be processed in some known way, e.g. in order to feed it into a loudspeaker.

If the bit stream is coded with just one code table, the distance between the raster points can be established quite simply by finding out from the side information of the bit stream

which table was used for coding. Depending on the coding, the distance might then be the length of the longest code word of this table, which could be set permanently in the coder. If the distance is the length of the longest code word actually occurring in a part of the bit stream to which a code table is assigned, this is communicated to the decoder in the side information which is assigned to the bit stream, and so on.

The decoder performs a resorting of the priority code words and also of the non-priority code words, e.g. by applying a pointer to the coded bit stream. If the raster distance is known to the decoder and the priority code words are arranged linearly with frequency, the decoder can jump to a raster point and read the code word which starts there. Once a code word has been read the pointer jumps to the next raster point and repeats the process just described. After all the priority code words have been read, the bit stream still contains the non-priority code words. If a linear arrangement of the priority code words and the non-priority code words in the bit stream was chosen, the non-priority code words are already arranged linearly with frequency and can be decoded and transformed back without further sorting.

If coding according to the third or fourth aspect of the present invention has been chosen, either scramble information can be transmitted as side information or the scrambled distribution is fixed a priori and is thus known to the decoder from the start. The same considerations apply to the fourth aspect. It is always possible to stipulate a fixed distribution or to choose a variable distribution which is communicated to the decoder as side information.

An advantageous way of determining and manipulating the priority code words will now be discussed. After establishing a raster for a coded bit stream, either by specifying the raster

distance when using just one code table or the raster distances when using a number of code tables, the priority code words must be so positioned in the raster that each priority code word coincides with a raster point.

According to a preferred embodiment of the present invention this positioning is achieved by inserting the code words sequentially into the essentially empty raster from a kind of sort table. A start is made with the first code word in the table. The priority code words can thus be influenced by the ordering of the code words in the table, priority code words always being those code words in the table with a place in the raster, i.e. for which raster points are available. For code words in the table for which there are no further raster points, there is no choice but to insert them in the remaining free places in the bit stream. These code words are thus not priority code words in the sense of the present invention.

The number of priority code words is not determined in advance. Priority code words are written until the memory available for the coded bit stream is full, i.e. until no further priority code word can be written. The size of the memory is equal to the total number of bits previously used for the spectral data, i.e. no further bits are required by the rastering. The memory is thus limited by the number of code words to prevent the coding efficiency falling off as a result of raster ordering. All the code words could, of course, be placed on raster points to make them error tolerant. However, this would lead to a marked decrease in the coding efficiency since the free bits remaining between the raster points are not used.

The first aspect of the present invention relates to determining the priority code words, i.e. the code words which represent the spectral values which are psychoacoustically impor-

tant compared with other spectral values. A psychoacoustically important spectral line is e.g. a spectral line which contains more energy than another spectral line. Generally speaking it can be said that the more energy a spectral line has the more important it is. Thus it is important that spectral lines with high energy are not disturbed and equally important that spectral lines with high energy do not result from errors.

Until now it has been assumed that the spectral lines with high energy are located primarily in the lower part of the spectrum. This is true in many cases but not in all. The present invention ignores this assumption by using an implicit indicator to estimate the energy of the coded spectral line in a code word, or of the spectral lines if a number of spectral lines are coded in a code word.

This indicator is the code book or code table, e.g. a Huffman code table, which is used. In the AAC standard eleven tables e.g. are used. The value ranges of these tables differ considerably. The maximum absolute values of the tables 1 to 11 are as follows:

1; 1; 2; 2; 4; 4; 7; 7; 12; 12; 8191.

As a result of these different value ranges, the maximum error depends on the table. Taking account of the sign for each table, which is either explicitly available in the table or is transmitted outside the table, the maximum error amounts to twice the cited absolute value. According to the present invention the determination of the priority code words is effected on the basis of the code table which is employed, the indicator being the highest absolute value and implicitly the code table number. At first code words whose code table has the greatest value range are considered. Then follow those code words whose code table has the second greatest value, and

so on. In the case of the AAC standard, therefore, table 11 is considered first, followed by tables 9 and 10 and concluding with tables 1 and 2 with the lowest priority. Priority code words, which are placed on raster points, are thus the code words in the sort table for which raster points are available.

An advantage of this method of determining the code words is the fact that no additional information has to be transmitted for the decoder since the tables which are used are transmitted in the side information and from this information the decoder can determine the code word sequence used during the transmission.

The second aspect of the present invention relates to the use of short (sampling) windows as opposed to long windows for transforming discrete-time samples of the audio signal into the frequency domain in order to obtain spectral values representing the audio signal. Short windows are defined in the AAC standard and also in the standard layer 3. In the case of short windows a number of short MDCTs are used instead of one long MDCT.

In the AAC standard a group of eight MDCTs each having 128 output values is used e.g. instead of an MDCT with 1024 output values. This results in an increase in the temporal resolution of the coder at the expense of the frequency resolution. Generally short windows are used for transient signals. If short windows are used with AAC for example, eight successive complete spectra, i.e. eight sets of spectral values, are obtained, each set of spectral values encompassing the whole spectrum. In contrast to the long windows, however, the distance between the spectral values is also eight times as big. This represents the diminished frequency resolution, which, however, is accompanied by a higher temporal resolution.

In the AAC standard a grouping is performed, i.e. groups are formed from the eight spectra. For each of these groups there is a set of scale factors. In the simplest case each group contains just one window. In this case eight scale factor sets must be transmitted. To achieve stronger compression, a plurality of windows is concentrated in a group in the AAC standard, generally taking account of psychoacoustic requirements. This reduces the number of scale factors to be transmitted, resulting in a better data compression. The spectral data are transmitted, i.e. written into a coded bit stream, sequentially group by group. Within the groups scale factor band interleaving is performed.

This may be demonstrated by the following example. Here there has been grouping into three groups. The first group contains two windows, the second group contains three windows and the third group also contains three windows. Each spectrum has 12 scale factor bands. The grouping is then as follows:

1st group, 1st window, 1st scale factor band
1st group, 2nd window, 1st scale factor band
1st group, 1st window, 2nd scale factor band
1st group, 2nd window, 2nd scale factor band

. . .

1st group, 2nd window, 12th scale factor band
2nd group, 3rd window, 1st scale factor band
2nd group, 4th window, 1st scale factor band
2nd group, 5th window, 1st scale factor band
2nd group, 3rd window, 2nd scale factor band

. . .

This arrangement is not suitable for presorting or inserting code words from the sort table in the raster, since if sequential insertion is employed the complete spectrum of the first group would be protected but the spectrum of the last group

would be completely unprotected. For this reason a presorting
according to the second aspect of the present invention is
carried out for short windows. In the case of the AAC standard
the grouping and the scale factor band approach are abandoned.
A new presorting is performed, this time in units of spectral
lines.

In a preferred embodiment of the present invention each unit
contains 4 spectral lines. In the AAC standard each window
therefore contains 32 units, corresponding to 128 spectral
lines. The spectral data are arranged as follows:

1st window, 1st unit

2nd window, 1st unit

. . .

8th window, 1st unit

1st window, 2nd unit

2nd window, 2nd unit

. . .

8th window, 2nd unit

1st window, 3rd unit

. . .

This presorting ensures that the individual spectral regions
of all the windows lie near one another, i.e. that low spec-
tral values are written according to frequency from the indi-
vidual sets of spectral values into the front area of the sort
table before the spectral values with higher frequency. If the
spectral values in the lower spectral region are particularly
important psychoacoustically, the cited presorting in the sort
table provides the basis for inserting the spectral values
from the sort table into the raster. With this presorting of
the code words, i.e. determining the priority code words,
there is no need to transmit any additional information since
the decoder knows from the side information that short windows

were used in this block or frame and the sort algorithm in the coder for generating the units is always fixed and is thus permanently programmed in the decoder.

It is important to note that the presorting of code words into a sort table corresponds to determining the priority code words since this table in itself determines which code words can, with a high degree of probability, be written to raster points since the code words which can, with a high degree of probability, be positioned on raster points, i.e. the priority code words, are those code words at the beginning, i.e. at the front or upper region, of the sort table.

Other than in the preferred embodiment this presorting is not performed by means of a sort table but by indexing the individual code words so as to specify the sequence in which the indexed code words are to be written into the bit stream.

From the AAC standard it is known that some code tables are two dimensional or four dimensional, i.e. that a code word codes two or four spectral values. It is therefore advantageous to group four spectral lines or a multiple thereof into a unit, since in this way code words which code the same frequency region can be sorted in direct succession to one another. The number of spectral lines from a unit is thus preferably divisible by the different dimensions of the code tables, i.e. the number of lines per unit must be a common multiple of the number of lines per code word and optimally the lowest common multiple.

The present invention becomes particularly efficient when the first and second aspects are combined. If resorting into units according to the present invention has been performed for short windows, this can be followed by priority code word determination by means of the code table indicator in which the

result of unit resorting is resorted again to ensure that the code words from higher code tables become priority code words which are positioned on fixed raster points so as to achieve a high degree of error security. This combination is not absolutely necessary, but it leads to the best results.